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Doy et al.

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(54) **SYSTEM AND METHOD FOR DETERMINING A GROUND SPEED OF A MACHINE**

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B60T 8/172 (2006.01)

(52) **U.S. Cl.**
CPC ***B60T 8/172*** (2013.01); *B60T 2210/36* (2013.01); *B60T 2250/04* (2013.01)

(58) **Field of Classification Search**
CPC E02F 9/2296; E02F 9/2029; E02F 9/2246; E02F 3/847; E02F 9/2253; E02F 3/437; E02F 9/2235; E02F 3/842; E02F 3/845; E02F 3/434; E02F 3/432; A01B 69/008; G05D 1/0278; G05D 2201/0202; G05D 1/027; G05D 1/0274; G01S 19/14; Y02T 10/7077
USPC 701/50
See application file for complete search history.

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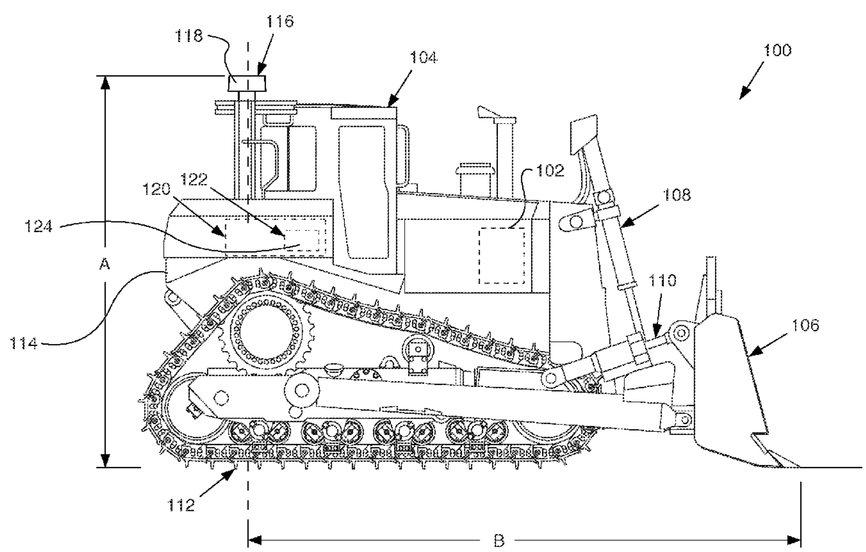
(57) **ABSTRACT**

The disclosure describes, in one aspect, a method for determining a machine ground speed. The method includes determining a first speed from a position determining system, determining a direction the machine is traveling at the first speed, determining a machine rate of inclination, and determining a compensated ground speed as a function of the first speed and the machine rate of inclination.

18 Claims, 2 Drawing Sheets



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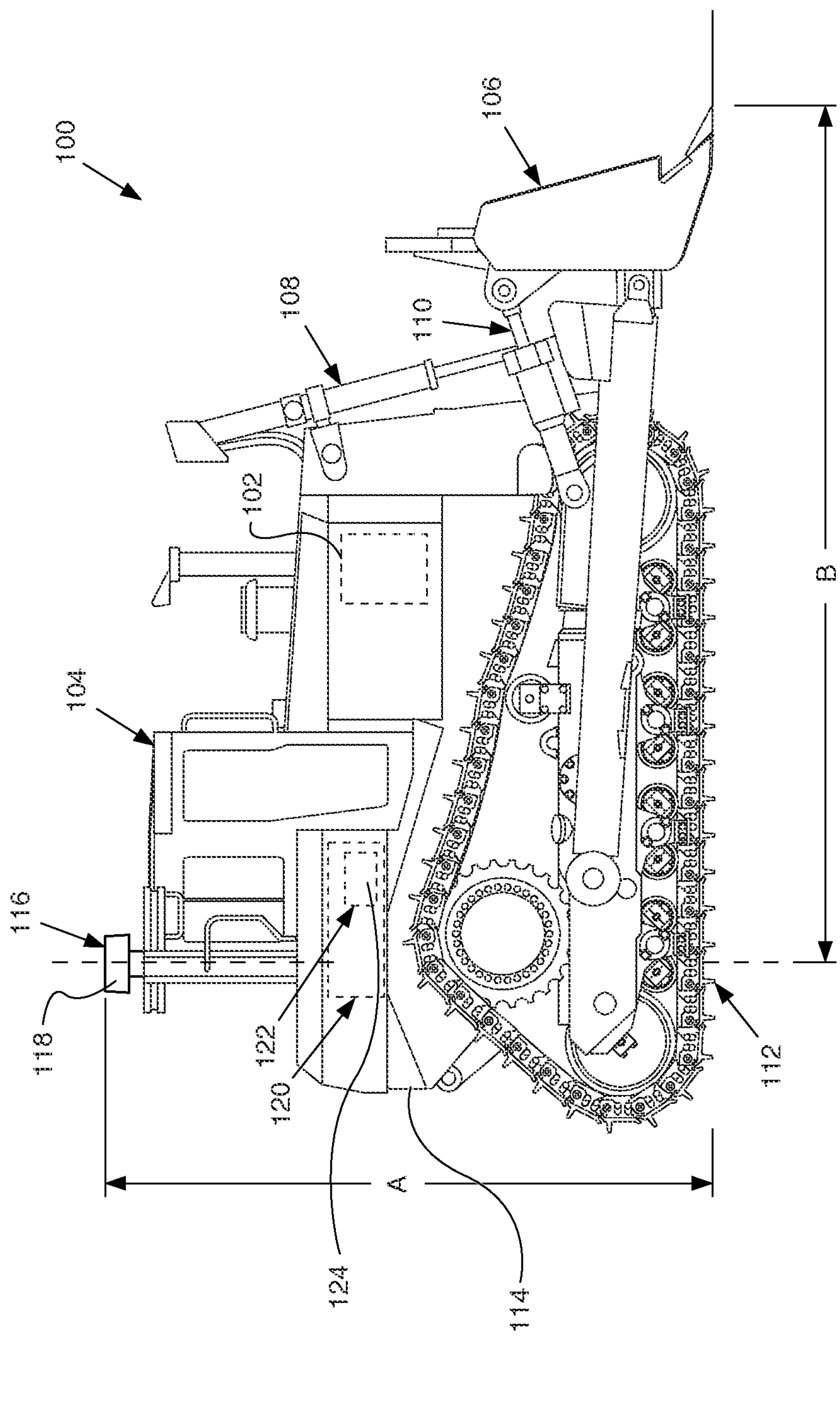
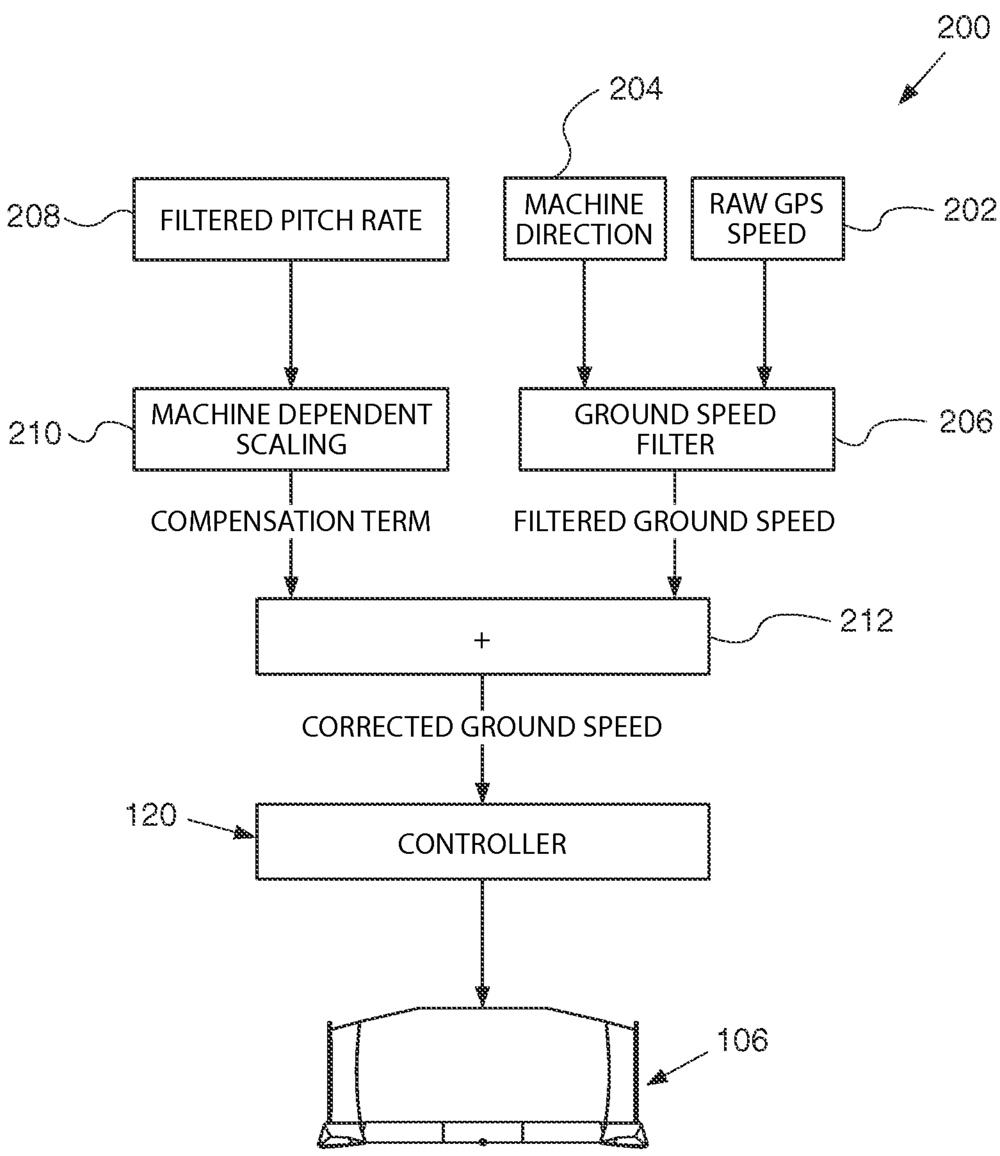


FIG. 1

FIG. 2


200
204
208
FILTERED PITCH RATE
MACHINE DIRECTION
RAW GPS SPEED
202
210
MACHINE DEPENDENT SCALING
GROUND SPEED FILTER
206
COMPENSATION TERM
FILTERED GROUND SPEED
+
212
CORRECTED GROUND SPEED
120
CONTROLLER
106

SYSTEM AND METHOD FOR DETERMINING A GROUND SPEED OF A MACHINE

RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from U.S. Provisional Application No. 61/424,969 by Nathaniel S. Doy et al., filed Dec. 20, 2010, the contents of which are expressly incorporated herein by reference.

TECHNICAL FIELD

This patent disclosure relates generally to a control system, and more particularly to systems and methods for determining a ground speed for controlling a machine component.

BACKGROUND

Earthmoving machines such as track type tractors, motor graders, scrapers, and/or backhoe loaders, have an implement such as a dozer blade or bucket, which is used on a worksite in order to alter a geography or terrain of a section of earth. The machine and/or the implement may be controlled by an operator or by a control system to perform work on the worksite such as achieving a final surface contour or a final grade on the worksite. Positioning the implement, however, is a complex and time-consuming task that requires expert skill and diligence if the operator is controlling the movement. Thus, it is often desirable to provide autonomous control of the machine and/or the implement to simplify operator control.

For autonomous control, it is sometimes necessary to determine the accurate ground speed of the machine to compare against a desired ground speed value for the control systems. Some machines use ground penetrating radar (GPR) and other ground based position systems to determine the ground speed. GPR components, however, are prone to failure, which may introduce errors in the ground speed determination and are often easily covered with dirt, which an operator must get out of machine, crawl under it, and remove the debris from the mounted radar. Further, radar components due to location can be damaged by rocks.

For example, U.S. Pat. No. 5,8640,480 to Jayaraman et al. ("Jayaraman") disclose a method for determining pitch and ground speed of an earth moving machine. Jayaraman discloses an automatic control system that includes a ground speed sensor that senses the ground speed of the earth moving machine and responsively produces a ground speed signal. Jayaraman teaches that the ground speed sensor is suitably positioned on the bulldozer and includes for example, a noncontacting ultrasonic or Doppler radar type sensor.

The disclosed systems and methods are directed to overcoming one or more of the problems set forth above.

SUMMARY

In one aspect, the disclosure describes, a method for determining a machine ground speed. The method includes determining a first speed from a position determining system, determining a direction the machine is traveling at the first speed, determining a machine rate of inclination, and determining a compensated ground speed as a function of the first speed and the machine rate of inclination.

BRIEF DESCRIPTION OF THE DRAWING(S)

FIG. **1** illustrates a side view of a machine having a control system in accordance with an exemplary embodiment of the present disclosure.

FIG. **2** is a flow diagram illustrating one embodiment of a control process in accordance with an exemplary embodiment of the present disclosure.

DETAILED DESCRIPTION

This disclosure relates to systems and methods for determining a ground speed of a machine. An exemplary embodiment of a machine **100** is shown schematically in FIG. **1**. The machine **100** may be a mobile machine that performs some type of operation associated with an industry such as mining, construction, farming, transportation, or any other industry known in the art. For example, the machine **100** may be a track-type tractor or dozer, as depicted in FIG. **1**, a scraper, or any other machine known in the art. While the following exemplary embodiments are described in connection with a dozer, it should be appreciated that the description applies equally to the use of the embodiments in other machines.

In an illustrated embodiment, the machine **100** includes a power source **102**, an operator's station or cab **104** containing controls necessary to operate the machine **100**, such as, for example, one or more input devices (not shown) for propelling the machine **100** and/or controlling other machine components. The machine **100** further includes an implement **106**, such as, for example, a blade, a bowl, a ripper, or a bucket for moving earth.

The one or more input devices may include one or more joysticks disposed within the cab **104** and may be adapted to receive input from an operator indicative of a desired movement of the implement **106**. The cab **104** may also include a user interface having a display for conveying information to the operator and may include a keyboard, touch screen, or any suitable mechanism for receiving input from the operator to control and/or operate the machine **100**, the implement **106**, and/or the other machine components.

The implement **106** may be adapted to engage, penetrate, or cut the surface of a worksite and may be further adapted to move the earth to accomplish a predetermined task. The worksite may include, for example, a mine site, a landfill, a quarry, a construction site, or any other type of worksite. Moving the earth may be associated with altering the geography at the worksite and may include, for example, a grading operation, a scraping operation, a leveling operation, a bulk material removal operation, or any other type of geography altering operation at the worksite.

The implement **106** may be moveable by one or more hydraulic mechanisms operatively connected to the input device in the cab **104**. The hydraulic mechanisms may include one or more hydraulic lift actuators **108** and one or more hydraulic tilt actuators **110** for moving the implement **106** in various positions, such as, for example, lifting the implement **106** up or lowering the implement **106** down, tilting the implement **106** left or right, or pitching the implement **106** forward or backward. In the illustrated embodiment, the machine **100** includes one hydraulic lift actuator **108** and one hydraulic tilt actuator **110** on each side of the implement **106** (only one side shown).

The power source **102** is an engine that provides power to ground engaging mechanisms **112** adapted to support, steer, and propel the machine **100**. The power source **102** may embody an engine such as, for example, a diesel engine, a gasoline engine, a gaseous fuel-powered engine, or any other type of combustion engine known in the art. It is contemplated that the power source **102** may alternatively embody a non-combustion source of power (not shown) such as, for example, a fuel cell, a power storage device, or another suitable source of power. The power source **102** may produce a mechanical or electrical power output that may be converted to hydraulic power for providing power to the machine **100**, the implement **106**, and to other machine **100** components.

The machine **100** further includes a frame or rigid body **114** disposed between the implement **106** and the ground engaging mechanisms **112**. A position determining system **116** adapted to receive and process position data or signals may be mounted to the rigid body **114** of the machine **100**. In some embodiments, the position determining system **116** may be mounted on or proximate to the top of the cab **104** at a distance A relative to the bottom of the ground engaging mechanisms **112** and a distance B relative to the tip of the implement **106**. The position determining system **116** may be a global position satellite (GPS) system **118**. The GPS system **118**, as is well known in the art, receives signals from a plurality of satellites and responsively determines a position of a receiver in a coordinate system relative to the worksite, that is, in a site coordinate system. The site coordinate system may be a Cartesian system having an x-coordinate, a y-coordinate, and a z-coordinate.

In addition to position data, the GPS system **116** may be adapted to process a corresponding speed of the receiver. The corresponding speed may be used to determine the speed of travel of the machine **100**; in other words, the GPS system **118** may be adapted to determine the travel speed or ground speed of the machine **100**. In some embodiments, the GPS system **118** may determine a three-dimensional position, for example, latitude, longitude, and height, and may determine a three-dimensional speed, for example, northward, eastward, and vertical speeds. In alternative embodiments, the position determining system **116** may include other types of positioning systems mounted to the rigid body in a plurality of locations, such as, for example, inertial navigational systems (INSs), and may include a plurality of methods for determining a corresponding ground speed without departing from the scope of this disclosure.

The machine **100** may further include a control system **120** operatively connected to the input device and to the hydraulic actuators **108**, **110** for controlling, for example, movement of the implement **106**. In some embodiments, the control system **120** may be operatively connected to the input device and to other machine components for controlling other operations of the machine **100**, such as, for example, connected to the ground engaging mechanisms **112** for controlling a speed of the machine **100**. The control system **120** may direct the implement **106** to move to a predetermined or target position in response to an operators' desired movement of the implement **106** for engaging the implement **106** with the terrain of the worksite. The control system **120** may further direct the implement **106** to move to a predetermined or target position indicative of an automatically determined movement of the implement **106**, based in part on, for example, an engineering or site design, a map, a productivity or load maximizing measure, or a combination of site design and productivity measure.

For precise control, such as, for example, to direct the implement **106** to move precisely in response to an automatically determined movement signal or command, the control system **120** may require certain predetermined or acquired data associated with the machine **100**, such as, for example, the ground speed and/or the pitch of the machine **100**. The control system **120** may include one or more sensors **122** operatively connected to or associated with the machine **100** for determining certain operational characteristics of the machine **100**, such as, for example, an inclination or pitch rate sensor **124** for determining an angle, inclination, or pitch of the machine **100** and/or a rate of change associated with the angle, inclination, or pitch of the machine **100**. The one or more sensors **122** may be located proximate to a pitch center of the machine **100**, such as, for example, near a transmission case (not shown) of the machine **100**. In some embodiments, the one or more sensors **122** may be embodied as an inertial measurement unit (INU) in an INS that measures linear and rotational degrees of freedom, such as, for example, pitch, yaw, and roll.

The control system **120** may be adapted to receive inputs from the input device, the position determining system **116**, and the sensors **122**, **124**. The control system **120** is further adapted to control or direct the movement of the implement **106** based at least in part on the inputs from the input device, the position determining system **116**, and the sensors **122**, **124**. It is contemplated that the one or more sensors **122** may in alternative embodiments include appropriate sensors adapted for determining roll rates and/or yaw rates to provide a three dimensional representation of the orientation of the machine **100** to determine ground speed in accordance with this disclosure.

The control system **120** may include one or more control modules (e.g. ECMs, ECUs, etc.). The one or more control modules may include processing units, memory, sensor interfaces, and/or control signal interfaces (for receiving and transmitting signals). The processing units may represent one or more logic and/or processing components used by the control system **120** to perform certain communications, control, and/or diagnostic functions. For example, the processing units may be adapted to execute routing information among devices within and/or external to the control system **120**.

Further, the processing units may be adapted to execute instructions, including from a storage device, such as memory. The one or more control modules may include a plurality of processing units, such as one or more general purpose processing units and or special purpose units (for example, ASICS, FPGAs, etc.). In certain embodiments, functionality of the processing unit may be embodied within an integrated microprocessor or microcontroller, including integrated CPU, memory, and one or more peripherals. The memory may represent one or more known systems capable of storing information, including, but not limited to, a random access memory (RAM), a read-only memory (ROM), magnetic and optical storage devices, disks, programmable, erasable components such as erasable programmable read-only memory (EPROM, EEPROM, etc.), and nonvolatile memory such as flash memory.

INDUSTRIAL APPLICABILITY

The industrial applicability of the systems and methods for determining a ground speed for the machine described herein will be readily appreciated from the foregoing discussion. Although the machine is shown as a track-type tractor, the machine may be any type of machine that performs at least one operation associated with, for example, mining, construction, and other industrial applications. Moreover, the systems and methods described herein can be adapted to a large variety of machines and tasks. For example, scrapers, backhoe loaders, skid steer loaders, wheel loaders, motor graders, and many other machines can benefit from the systems and methods described.

In accordance with certain embodiments, FIG. **2** illustrates an exemplary embodiment of the control system **120** and the process of determining the ground speed of the machine **100** (**200**). The control system **120** is adapted to receive a speed associated with the machine **100** from the GPS system **118** (Step **202**). The GPS system **118** provides the speed of the machine **100** based in part on the speed at the GPS system **118** receiver mounted to the body **114** of the machine **100**. The control system **120** is adapted to receive direction information associated with the direction in which the machine **100** is traveling (**204**). The speed information received from the GPS system **118** may be filtered, such as, for example, using a weighted moving average (Step **206**).

In some embodiments, since the GPS system **118** is mounted to the body **114** of the machine **100**, which may be on or near the top of the cab **104**, the GPS system **118** receiver may be located at a significant distance away from the center of gravity of the machine **100**. This distance away from the center of gravity may introduce errors when the speed is determined by the GPS system **118**. The errors may be associated with or correlated with the pitch of the machine **100**. Thus, the control system **120** is adapted to receive a pitch rate from the one or more sensors **122** embodied as the pitch rate sensor **124** (Step **208**). In some embodiments, the pitch rate data or signal may be processed to eliminate noise and bias, such as, for example, using high pass and low pass filters.

Further, the distance the GPS system **118** is away from the center of gravity is a function of the size of the machine **100**. Consequently, the magnitude of the error when determining the speed may be proportionate to the distance the GPS system **118** is away from the center of gravity. The control system **120** is adapted to determine a machine dependent scale factor for adjusting the speed determined by the GPS system **118** as a function of the pitch rate (Step **210**). The factor may be determined from the following equation:

$$\text{factor} = \frac{\left(\frac{2\pi[\text{rad}]}{360[\text{deg}]}\right)\text{lever\_arm}[\text{mm}]}{1000\frac{[\text{mdeg}]}{[\text{deg}]}}$$

The lever_arm, which is essentially the distance between the pitch rate sensor **122** and the GPS system **118** receiver, may approximate the distance the GPS system **118** is away from the center of gravity or the center of pitch. The above factor may be used to determine a scaled pitch rate compensation term, which is based in part on the size of machine **100**, to be used for addressing the errors introduced by the GPS system **118** as discussed above. The scaled pitch rate compensation term and the filtered speed are summed to provide a corrected ground speed (Step **212**). The control system **120** is adapted to receive the corrected ground speed and may use the corrected ground speed for more precise control, for example, of the implement **106** in response to an automatically determined movement signal or command. It is contemplated that the corrected ground speed may be used by the control system **120** to control other machine operations that require an accurate ground speed, such as, for example, to control the speed of the machine **100**.

It will be appreciated that the foregoing description provides examples of the disclosed systems and methods. However, it is contemplated that other implementations of the disclosure may differ in detail from the foregoing examples. All references to the disclosure or examples thereof are intended to reference the particular example being discussed at that point and are not intended to imply any limitation as to the scope of the disclosure more generally. All language of distinction and disparagement with respect to certain features is intended to indicate a lack of preference for those features, but not to exclude such from the scope of the disclosure entirely unless otherwise indicated.

Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context.

Accordingly, this disclosure includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the disclosure unless otherwise indicated herein or otherwise clearly contradicted by context.

We claim:

1. A method for controlling a component of a machine based on a compensated ground speed, the method comprising:
- determining a first speed from a position determining system;
- determining, by a microprocessor, a direction the machine is traveling at the first speed;
- determining, by an inclination sensor, a machine rate of inclination;
- determining, by a microprocessor, a compensated ground speed as a function of the first speed, the machine rate of inclination, and a compensation term; wherein the compensation term is determined as a function of a distance between a component of the position determining system and a location of a pitch center of the machine; and
- controlling the machine component based on the compensated ground speed.

2. The method of claim **1**, wherein determining the machine rate of inclination includes multiplying a pitch rate received from an inclination sensor by the compensation term.

3. The method of claim **2**, wherein determining the compensated ground speed includes summing the machine rate of inclination and the first speed.

4. The method of claim **3**, wherein determining the compensated ground speed includes calculating a weighted moving average of the first speed for a predetermined number of samples.

5. A control system for controlling a component of a machine based on a compensated ground speed, comprising:
- a controller operatively connected to a machine component, a position determining system, and an inclination sensor, the controller adapted to:
- determine a first speed from the position determining system;
- determine a direction the machine is traveling at the first speed;
- determine a machine rate of inclination from the inclination sensor;
- determine a compensated ground speed as a function of the first speed, the machine rate of inclination, and a compensation term; wherein the compensation term is determined as a function of a distance between a component of the position determining system and a location of a pitch center of the machine; and
- control the machine component based on the compensated ground speed.

6. The control system of claim **5**, wherein the controller is further adapted to:

determine the machine rate of inclination by multiplying a pitch rate received from the inclination sensor and the compensation term.

7. The control system of claim **6**, wherein the controller is further adapted to:

determine the compensated ground speed by summing the machine rate of inclination and the first speed.

8. The control system of claim **7**, wherein the controller is further adapted to:

determine the compensated ground speed by calculating a weighted moving average of the first speed for a predetermined number of samples.

9. A control system for controlling a component of a machine based on a compensated ground speed comprising:

a controller operatively connected to a machine component, a GPS system, and a pitch rate sensor, the controller adapted to:

determine a first speed from the GPS system;

determine a machine pitch rate from the pitch rate sensor, the pitch rate sensor is mounted at a location proximate to a machine center of gravity;

determine the compensated ground speed as a function of the first speed, the machine pitch rate, and a compensation term, wherein the compensation term is a function of a distance between the GPS system and the location of the pitch rate sensor; and

control the machine component based on the compensated ground speed.

10. The control system of claim **9**, wherein the GPS system is mounted to a body of the machine.

11. The control system of claim **10**, wherein the GPS system is located proximate to the top of a cab of the machine and at a distance from the machine center of gravity.

12. The control system of claim **11**, wherein the GPS system is located on the top of the cab of the machine.

13. The control system of claim **9**, wherein the controller is further adapted to:

determine the compensated ground speed by summing the machine pitch rate and the first speed, wherein the machine pitch rate includes multiplying the compensation term and a pitch rate received by the pitch rate sensor.

14. The control system of claim **9**, wherein the machine component is at least one of an implement or a ground engaging mechanism.

15. The method of claim **1** wherein the machine component is an implement.

16. The method of claim **1** wherein the machine component is a ground engaging mechanism.

17. The control system as claimed in claim **5** wherein the machine component is an implement.

18. The control system as claimed in claim **5** wherein the machine component is a ground engaging mechanism.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,199,616 B2
APPLICATION NO. : 13/316698
DATED : December 1, 2015
INVENTOR(S) : Doy et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the claims

Column 8, line 23, claim 17, delete "The control system as claimed in claim 5" and insert -- The control system of claim 5 --.

Column 8, line 25, claim 18, delete "The control system as claimed in claim 5" and insert -- The control system of claim 5 --.

Signed and Sealed this
Eighteenth Day of October, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office